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# Digital Coherent Detection of Multi-Gigabit 16-QAM signals at 40 GHz Carrier Frequency using Photonic Downconversion

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**Abstract** We experimentally demonstrate detection of multi-gigabit 16-QAM modulated signals, of up to 4 Gb/s, at a 40 GHz carrier frequency by combining photonic downconversion and low bandwidth electronics.

## Introduction

Currently, there is a rapid increase and interest in new radio-over-fibre (RoF) technologies capable of enabling high capacity wireless access links<sup>1,2</sup>. The current trend is moving towards mm-wave frequencies, where complex modulation formats (QPSK, QAM<sup>2,3</sup>) and multiplexing schemes such as OFDM can be used in order to reach multi-gigabit capacities. Most of the reported works so far, focus on the photonic generation of multi-gigabit mm-wave signals<sup>1-3</sup>, i.e downstream channel. However, the demodulation of signals at mm-wave frequencies still poses many technical challenges since it requires very high-speed and linear radio-frequency (RF) electronics<sup>1-3</sup>. It is therefore important to overcome the limitations of detection electronics and smoothly extend the operating frequency range of RoF links to mm-wave frequencies. Additionally, the uplink direction (from the antenna base-station towards the central office) presents a challenge in order to make it robust, flexible and yet with low complexity, while providing full bidirectionality and high bandwidth operation.

In this contribution, we demonstrate an uplink channel approach for detection of multi-gigabit mm-wave radio-over-fibre signal without the need for high frequency electronics. To the best of our knowledge, this is the first report on the use of photonic downconversion for detection of 16-QAM modulation format at 40 GHz carrier frequency, with up to 4 Gbit/s data signal bit-rates and digital coherent detection. Using the photonic downconversion (PDC), the mm-wave signal is downconverted to approximately 1.6 GHz bandwidth, where signal digitization is performed, followed by off-line digital signal processing.

## Uplink approach with photonic downconversion

Although complex modulation formats allow for better

bandwidth utilization, they require high RF power levels and a high-degree of linearity<sup>1-3</sup>. We therefore use an optical phase modulator at the antenna base station, see Figure 1, for transport of the multi-gigabit mm-wave signal from the antenna base station to the central office. This approach results in a simple and robust configuration as the system benefits from the inherent linearity of optical phase modulation and absence of bias voltage<sup>4</sup>. Optically phase modulated RoF systems require, though, a linear coherent receiver. Even though it is more complex than a conventional direct detection scheme, it offers several advantageous features such as modulation format transparent optical receiver front end, linear demodulation and linear impairment compensation by postdetection digital signal processing.

## Experimental set-up

The experimental set-up for a phase modulated radio-over-fibre optical link employing PDC is shown in Fig. 1. The transmitter consists of a tuneable external cavity laser (ECL) at 1550 nm with an average output power of +10 dBm and <400 kHz linewidth. A 16-QAM signal is generated using a 15-bit arbitrary waveform generator (AWG) at 1.25 GSa/s, generating in-phase (I) and quadrature (Q) signal components. A vector signal generator (VSG) is used to perform up conversion to 40 GHz RF carrier frequency, with an output power of +16 dBm (4 V<sub>pp</sub>). The VSG is used to drive an optical phase modulator (PM), with a V<sub>π</sub> of 14 V at 40 GHz frequency. The optically phase modulated signal is transmitted through 40 km of standard single mode fiber (SMF) and detected using a coherent receiver, consisting of a 90° optical hybrid and two pairs of balanced photodiodes. The pulsed local oscillator (LO) is generated by gating light from a LO Continuous Wave (CW) laser source (linewidth ~100 kHz) and by applying a sinusoidal RF signal to an Electro-Absorption Modulator (EAM). The

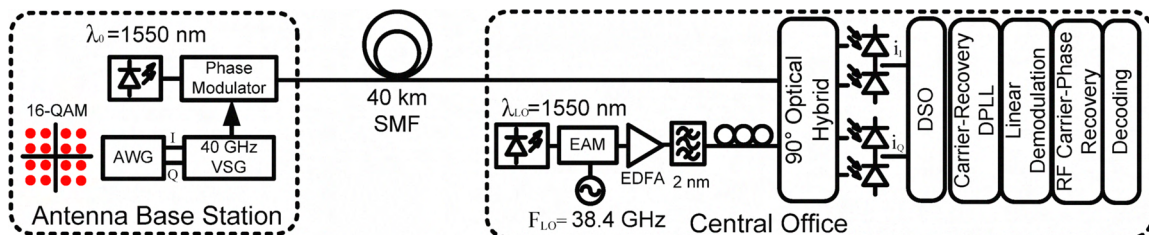
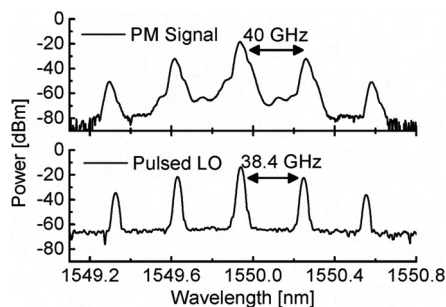


Fig. 1: Experimental set-up

wavelength of the LO CW laser source is set to 1550 nm and tuned to match the transmitter wavelength. The frequency of the applied RF signal is  $F_{LO}=38.4$  GHz, with 18 dBm RF power and a bias voltage of 2 V in order to obtain the highest extinction ratio of the pulses. The generated optical pulses are subsequently amplified by an EDFA and thereafter filtered in order to remove amplified spontaneous emission which lies outside the signal bandwidth. The average output power of the optical pulse train is set to 0 dBm, in order to operate within the linear regime of the photodiodes of the coherent receiver. Due to the mixing process in the coherent receiver, the original data signal at 40 GHz RF carrier frequency will be downconverted to an IF frequency:  $F_{IF}=F_{RF}-F_{LO}=1.6$  GHz. The output signals of the balanced photodiodes are then digitized using an 8 bits real time sampling-scope with 3 GHz analog bandwidth. The demodulation algorithms consist of carrier recovery digital PLL, linear demodulation, RF carrier phase recovery and symbol decision<sup>4</sup>. The frequency difference between the transmitter and LO laser, measured to be up to 1 GHz, can be successfully removed by the carrier-recovery digital PLL.

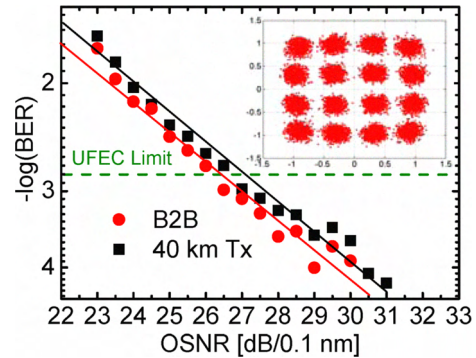


**Fig. 2:** Spectra of the phase-modulated (PM) signal at 40 GHz with 1 Gbit/s 16-QAM and pulsed local oscillator (LO) at 38.4 GHz.

## Results

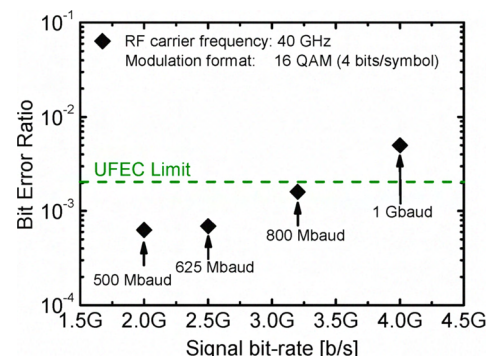
The optical spectra of the data signal and pulsed LO are shown in Figure 2. The peaks of the spectra are separated at 40 GHz for the optical data signal, and 38.4 GHz for the LO, so the resulting downconverted frequency component is at approximately 1.6 GHz. Figure 3 shows the bit-error-rate (BER) as a function of the optical signal-to-noise ratio (OSNR) for back-to-back (B2B) and after 40 km of transmission over SMF. The resulting bit-rate of the 16-QAM signal is 1 Gb/s. After fiber transmission of 40 km, we observe an OSNR penalty of only ~0.5 dB after using digital dispersion compensation. In figure 3, we also include as an inset an example of the constellation of the demodulated 16-QAM signal for 30 dB OSNR. The constellation points look clear and well separated.

In order to test the performance of the detection scheme for bitrates up to 4 Gb/s the 15-bits 1.25 GSa/s AWG is replaced with 12 GSa/s AWG



**Fig. 3:** BER as a function of the OSNR for back-to-back and transmission over 40 km of SMF. Top-right: Constellation of demodulated 1 Gbit/s 16-QAM at 30 dB OSNR

with 8-bits resolution. Figure 4 shows the results for the BER as a function of the increasing bitrate. For the bitrates of up to 3.2 Gbit/s, we are able to demodulate the signals with error rate below the threshold for forward error correcting coding (FEC). For the bitrates above 3.2 Gb/s, we are still able to perform signal demodulation, however, the BER is above the FEC limit, mainly due to the limited bandwidth and linearity of the I and Q mixer of the used VSG. We believe that for 1 Gbaud the signal error rate below the FEC limit could be obtained by using equalization algorithms.



**Fig. 4:** BER as a function of generated bit-rate for 16-QAM modulation format at 40 GHz RF carrier frequency

## Conclusions

Considering the UFEC limit of  $2 \cdot 10^{-3}$ , error free detection of 16-QAM signals with 40 GHz RF carrier frequency, for the total bit-rates up to 3.2 Gb/s is demonstrated. To the best of our knowledge, this is the first report on demodulation of advanced modulation formats at 40 GHz RF carrier frequency where no highly linear and complex RF electronic components are needed.

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